LAVOISIER'S FUNDAMENTAL CONTRIBUTION TO STRATIGRAPHY[1]

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ABSTRACT

Antoine Lavoisier's memoir of 1789 entitled "General observations on the recent marine horizontal beds and on their significance for the history of the earth" is the first detailed account of the fundamental principle of transgressive and regressive overlaps, usually attributed to Amedeus W. Grabau (1906).

In this major contribution to stratigraphy, Lavoisier, through his explanation of the significance of basal conglomerates, also reached the modern concept of sedimentary cycle. He furthermore described the mechanical distribution of littoral sediments by decreasing grain-size with increasing depth and distance from shoreline, and related it to the idea of a shore profile of equilibrium.

The detailed sections which accompanied Lavoisier's essay gave the first outline of a correct classification of the Tertiary deposits of the Paris basin.

INTRODUCTION

The basic principle of transgressive and regressive overlaps in stratigraphy is

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usually attributed to Amadeus W. Grabau (1906). The comprehensive character of his paper seems to indicate that Grabau considered his approach as completely original. He certainly did not realize that the famous chemist Antoine Lavoisier had published a memoir (1789) which contained the first modern discussion and illustration of the same concept in almost identical manner.

This major contribution of Lavoisier to stratigraphy has apparently escaped completely the attention of geologists and historians of science alike. The purpose of this paper is to make available to scientists the first English translation of this rare and important memoir accompanied by a modern redrafting of the original plates. This presentation is preceded by a brief analysis of Lavoisier's geological background and followed by a discussion of some aspects of his work.

A rehabilitation of Lavoisier as a geologist seems imperative for a correct understanding of the history of geology and particularly of the fundamental principles of stratigraphy.

LAVOISIER'S GEOLOGICAL WORKS

The chemical works of Lavoisier unquestionably represent his major claim to scientific fame but if this great scientist had not dedicated himself to chemistry he might have become one of the most famous founders of geology.

Lavoisier probably acquired the elements of geology and mineralogy while attending between 1762 and 1764 G. F. Rouelle's chemical lectures (Smeaton, 1963). This opinion is supported by the fact that in his publications Lavoisier generally cited Rouelle in a geological context.

Before Lavoisier turned seriously to chemistry, about five years after completing Rouelle's course, he was the very active and diligent coworker of Guettard in the great project called *Atlas et description minéralogiques de la France* (1780). With the exception of the memoir translated in this paper, all the geological and mineralogical works of Lavoisier remained as manuscripts or their practical results have been incorporated in the first 16 sheets of the atlas.

D'Archiac (1864) was able to examine his manuscripts and field notes written between 1764 and 1766 and dealing with several regions of France, particularly in the North. If these observations had been coordinated and published at the same time as the sheets, France would have possessed the most advanced geological document of that time. His field description of traverses in all directions between the Loire, Belgium, and the Vosges indicated perfectly the relationships of beds, particularly those above the chalk. All the local sections were measured and described in great detail. From time to time they were assembled together and abstracted for each natural region.

Lavoisier also took part in the graphical preparation of the atlas, as may be gathered from reports he sent in 1772 to Mr. Bertin, then minister of State who sponsored the great project with all his political power. However the only graphical result which seems to be dated of that time and could be attributed to him is the *Tableau de l'atlas géographi-minéralogique de France, entrepris par ordre du Roi* (a sheet with no date and no author's name). It is a map of France divided into 214 sections corresponding to the number of sheets the atlas was supposed to have. On the margin of the sheet is a *Table explicative des caractères minéralogiques* consisting of 211 symbols of which 18 deal particularly with the occurrence of certain fossils (Belemnites, Ammonites, fish, sea urchins, bivalve and univalve shells, crustaceans, crinoids, bones, and petrified wood). No map has ever been made in which mineralogical symbols included such a number of useful features.

This unusual background in field geology provided Lavoisier with a very acute insight into the general laws of stratigraphy clearly demonstrated in his memoir of 1789. Even if most of Lavoisier's geological work has remained unpublished or is still difficult to distinguish from that of Guettard, this single publication in geology is largely sufficient to establish his fundamental contribution.

LAVOISIER'S MEMOIR

General Observations on the Recent Marine Horizontal Beds and on Their Significance for the History of the Earth

A part of the materials which are present at the surface in the lower parts of the earth and as far down as we can observe, occur in horizontal beds. Immense quantities of marine organisms of all kinds are present in them which demonstrate that the sea has covered in the remote past a great part of the earth that is now inhabited.

A more detailed examination of the arrangement and composition of these beds suprisingly reveals features which indicate at the same time order, uniformity and quiet as well as disorder and movement.

For instance, at a given place accumulations of shells may occur among which are thin and fragile ones. Most of them display no traces of abrasion and appear in the same condition as they were upon death of the animal they enclosed. The elongate shells are lying horizontally and essentially in the position determined by their center of gravity. The associated depositional features indicate either gentle movements related to organic activity or a completely quiet environment.

An entirely different situation occurs a couple of feet above or below the bed in which the previous observations were made. Remnants of living organisms have been replaced by well-rounded pebbles which demonstrate the effects of a long period of strong agitation. It is the picture of a stormy sea thundering against the shore and rolling considerable quantities of pebbles. How can these contradictory observations be conciliated and such different effects ascribed to the same factor? How could the agitation which has abraded quartz, rock crystal and the hardest rocks into rounded pebbles, preserve at the same time fragile and light shells?

The investigation of the horizontal beds shows another very remarkable feature. Sand and calcareous materials do not usually occur together or at least only under particular circumstances and close to their points of contact. Most of the sands, especially the fine ones, do not contain any calcareous earth and conversely the chalk and most calcareous stones are typically devoid of sand or siliceous earth.

At first glance I could not understand this contrast of quietness and movement, of organization and disorder, of separation and association. However, through repeated observation of the same features in different places and under different circumstances, it occurred to me that such extraordinary facts could be explained in a simple and natural manner. Therefore the major natural laws responsible for the genesis of the horizontal beds could also be established. I have pondered for a long time on my hypothesis which now has reached a sufficient stage of completion for presentation to the Academy.

Scientific problems can be presented in two ways. In the first one the observed facts are traced back to their causes; in the second an original assumption is made and the observed facts are shown to fit exactly the former. This latter procedure, although rarely followed in the search for new truths, is nevertheless useful for teaching because it avoids difficulties and disgust among students. I have used it in the series of geological memoirs which I am planning to present to the Academy in the near future.

Sea water would be perpetually stagnant if wind action, ebb and flow, and changes of temperature did not exist. It would be submitted only to local and accidental movements due mainly to the action of living organisms. Therefore only the three above-mentioned factors can be responsible for the movements of sea water. Wind action is a superficial process which generates movement essentially by friction along the interface of the two fluids. Being necessarily slowed down by the resistance of the underlying layers, it decreases rapidly with increasing depth. Actually wind action does not extend practically beyond 10 to 12 ft depth.

Similarly restricted are the movements due to changes of temperature. They cannot be very rapid and experiments furthermore have demonstrated that sea water at a certain depth has an almost constant temperature. Therefore changes of temperature cannot generate agitation or any appreciable movements on the sea bottom.

Finally, according to Mr. de la Place, ebb and flow which is responsible for considerable damage along our coasts, generates at sea only very small oscillations which are even further reduced by the reciprocal friction of the molecules of water.

A trip to Cherbourg after writing this memoir gave me the opportunity to make with Mr. Meusnier new observations confirming the facts just mentioned. The range between high and low tide along that coast is approximately 20 ft. In this interval and at the most 10 to 12 ft below, the sea destroys all the obstacles set against it. The rolling of pebbles is also limited to the same vertical span of about 32 ft. However, rounded pebbles can form only wherever the slope of the shore is steep enough for their rolling down by gravity after having been tossed upslope by the waves. Through the endless repetition of this process, the pebbles are gradually rounded by abrasion of their corners, reduced in size and eventually converted into sands of variable grain size.

The dike of loose stones constructed in front of Cherbourg is by itself a striking demonstration. In spite of its enormous accumulation of stones, it could never be elevated above low-tide level. The waves destroying every obstacle in their path have arranged the loose stones of the dike into a talus 1 ft high and 10 ft wide which corresponds to an equilibrium between the resistance of the stones and the effort of the sea to lift them. The action of the sea, as mentioned before, does not extend beyond 10 to 12 ft below low-tide level, and with increasing depth quiet conditions rapidly prevail.

Since the action of the three factors which can agitate sea water is limited to its surface, only very weak bottom currents can exist. Therefore the organisms which lived on the bottom of the sea or at a certain distance from the shore and their enclosing layers, should present the picture of a quiet environment. Shells, even the most fragile ones, should occur intact and their position should display only the effects of the undisturbed action of gravity.

Conditions should be entirely different close to the shoreline. The effects of ebb and flow combined with the resistance of the coastlines and favorable or unfavorable wind action should give to the waters the high energy with which they come thundering against the shore. Such a powerful and endlessly repeated movement should easily abrade the corners of the hardest rocks and pile them up as heaps of pebbles.

The logical conclusion deduced from these first observations is that two very distinct kinds of beds should exist in the mineral kingdom. The first ones have been formed at great depth in the open sea and in agreement with Mr. Rouelle should be called *pelagic beas*. Those belonging to the second kind have been formed along the coasts and should be called *littoral beds*. These two kinds of beds ought to have very distinct properties which would prevent their confusion. The former should display masses of calcareous material as well as shells and remains of marine organisms slowly accumulated in a quiet environment through an immense sequence of years and centuries. The latter beds on the contrary should display a picture of movement, destruction and turmoil. They are indeed parasitic deposits built at the expense of the coasts and entirely different from those slowly deposited in the open sea, by the action of the living organisms.

The distinction of these two kinds of beds, which occured to me almost at the beginning of my interest in geology, explains at once the apparent confusion displayed by the areas consisting of horizontal layers. This distinction leads to numerous conclusions which will be successively presented to the reader.

Independently from the characteristic features which express an agitated or quiet environment and distinguish, even at first glance, *littoral* from *pelagic* beds, there are additional ones which result also from the same factors. The pelagic beds deposited in the open sea should be and are in fact composed of pure calcareous matter resulting from the accumulation of shell-bearing organisms without any admixture of foreign particles. The littoral beds formed at the coast, on the contrary, can display a great variety of composition depending on the nature of the coasts themselves. Only organisms capable of attaching themselves strongly to rocks are present in these beds, because the agitation would destroy all those weakly built or provided with thin shells.

Further thinking implies that the constitutive materials of the littoral beds should not occur indiscriminately mixed but on the contrary should be distributed in accordance with certain laws. Since the movement of sea water decreases readily from the surface downward to a depth of at least 40 to 50 ft, a definitive washing process similar to that used in the treatment of ores, should operate along the sea shore. This washing should even increase in extent as the steepness of the slope decreases. The coarsest materials like the pebbles should occupy the highest part and mark the limit of the high-tide. Below, the coarse sands, products of further abrasion of the pebbles should occur. Further down slope, in less agitated conditions, the fine sands should be deposited. Finally, the lightest and more divided materials like clay and siliceous earth in a pulverized state which remain an appreciable time in suspension should be deposited at a rather great distance from the coast at depths where agitation is almost non-existent.

The slope of the talus built by these materials is not random. It depends on several factors; specific gravity of sea water, degree of agitation at different depths, variable state of division and specific gravity of the transported molecules, etc. By knowing these data, the inclination of the submarine slope could be calculated from the beach to a certain distance offshore and reciprocally by knowing the inclination and the other data, the movement of sea water at different depths could be determined.

But without entering the calculations which the most learned analysis would necessitate, it is seen in general that the curve of the sea bottom from the shoreline to the open sea should fairly approximate a segment of parabola, the axis of which would be parallel to the horizon. In other words, the inclination of the coast to the horizon at the limit of the open sea should approach 45°. Thereafter it should go, diminishing, to the place where the sea water is in absolute repose and from there its base should tend to become absolutely horizontal.

Figure 1 shows the situation along a seashore consisting of chalk as in Upper Normandy and in the corresponding coasts of England. I will discuss somewhere else the effects produced by a coast of variable composition.

The cliff consists of chalk with chert nodules of irregular shape scattered at random or occurring in horizontal layers. The continuous undermining action of the sea at the foot of the cliff keeps its face almost vertical. After each successive landslide of chalk and chert nodules, the debris has been sorted by the movement of the waters. The very light and finely divided calcareous earth or chalk remained a long time in suspension and eventually has been deposited far out at sea, at M, either pure or mixed with very divided siliceous earth. The chert nodules exposed on the shore have been broken into angular fragments which after further rounding into pebbles remained in B-D-F-G, the high-tide line. The siliceous materials produced by the abrasion have been carried to a variable distance depending upon their size and accordingly formed coarse sand, fine sand or an impalpable dust of siliceous earth.

Figure 1 shows below the pebbles, the coarse sand deposited between H and I, the finer sand between I and L, the impalpable argillaceous or siliceous earth between L and M. The same argillaceous earth mixed with finely divided calcareous earth builds a kind of marl between M and N. This sequence of deposits (H-L-L-M-N) formed along the coast represents the *littoral beds.* Finally, at X the pelagic calcareous beds formed in open sea begin. They extend further down into deeper water and tend to become more and more horizontal. Their composition, particularly at N, still depends more or less on the nature of the cliff because they are not sufficiently distant from it.

In many places in Normandy, the chert nodules turned into pebbles have been accumulated today as a kind of protective wall at the foot of the cliff. However, this wall gradually decreases in size year after year through abrasion of the pebbles. Therefore, one day the cliff will be deprived of effective protection and again undermined. New landslides will occur providing materials for renewed washing. Chert nodules will again be rounded into pebbles which in turn will disappear.

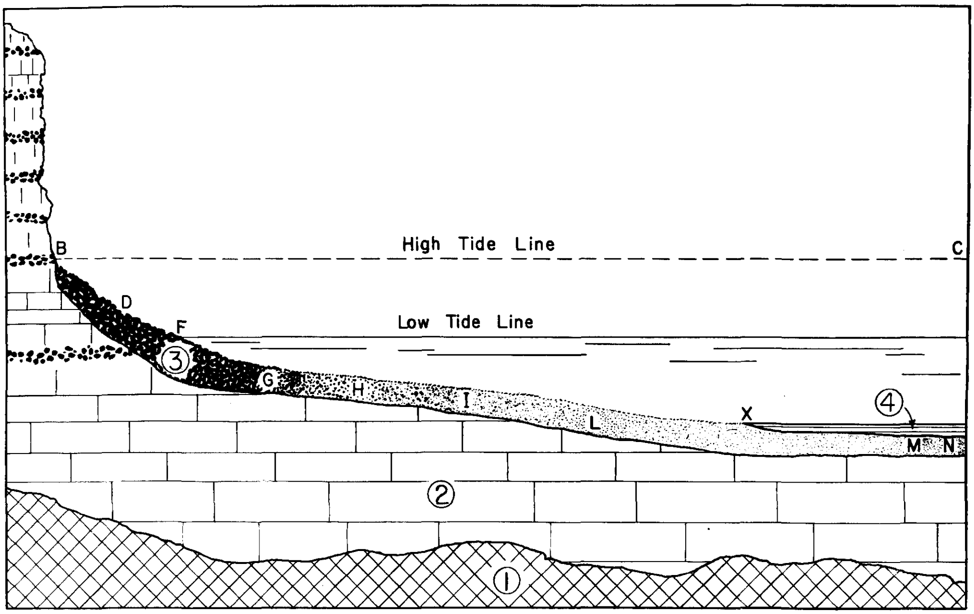

FIGURE 1. Shoreline erosion of the cliffs of chalk and related deposition of gravels, sands, and clays (littoral beds).
1. Substratum of older rocks.
2. Chalk with or without chert nodules (also called lower calcareous pelagic beds).
3. Littoral beds.
4. Pelagic beds.

Ultimately an equilibrium should have been reached and the natural slopes should have resisted the action of the sea and should have protected effectively the coast if the sea had always been enclosed within the same boundaries, if its level had been constant, if for a given reason it had not been in the very remote past submitted to advances and retreats. Obviously this movement of the sea has not yet been demonstrated either by calculation or by observation. Nevertheless, I would like to consider this hypothesis and discuss its possible results and consequences. My assumption would become a reality should I succeed in demonstrating that it fits perfectly with all the observed facts. Therefore we are not going to consider the effects of a static body of water but those of a sea which very slowly overflows its basin and afterwards returns into it in accordance with certain laws.

If the sea encroaches over the coast and its level rises of an amount equal to BS (fig. 2), the cliff which existed at AB will be undermined at the level of S. Landslides will take place until a new cliff HR will be formed at the SR end of the high-tide line. If sea level continues to rise gradually of amounts equal to ST, TV and VX, the cliff will retreat to IQ, KP and so on until the rising of the sea will have reached its upper limit. Supposing the latter to be MY, the corresponding cliff would be at LM and the upper surface of the chalk originally along the line of L-K-I-H-A will now be along M-P-Q-R-B. Furthermore, this surface will be covered with beds of pebbles, sands and marls, in other words of *littoral beds* consisting of materials which originated from the destruction of the rocks originally located inside the line L-K-I-H-A-M-P-Q-R-B. Therefore the encroachment of the sea on the coasts has a simultaneous destructive and constructive action. If the older rocks were completely overlain by chalk, the bottom of the sea from the

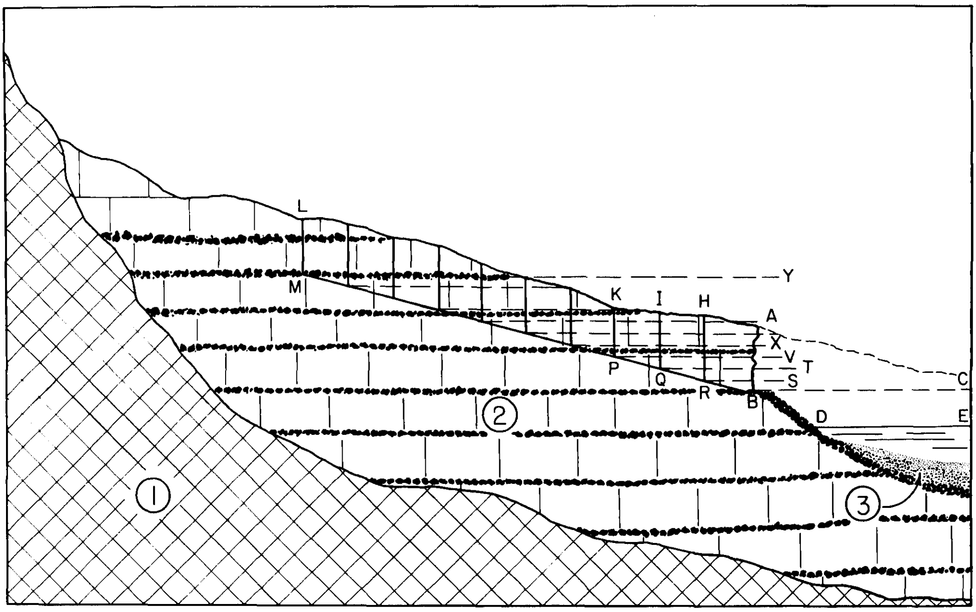

FIGURE 2. Shoreline variations in the hypothesis of a very slow rising of sea level. Same legend as preceding figure.

coast to a distance of 20 to 30 leagues offshore should display the situation shown in figure 3. The substratum of chalk should be covered by a layer of parasitic or littoral beds B-H-I-L-M-N consisting of rounded pebbles, sand and marl.

I have pointed out earlier the absence of shells and of marine organisms in general along a pebbly coast, because they should be rapidly broken and destroyed by the movement of the waves and particularly by the action of the pebbles. Generally speaking, marine organisms, particularly those carrying a weak protection, should not find a favorable environment near shore. Indeed only species should occur which can attach themselves strongly to the rocks or debris of shells belonging to dead animals which were thrown against the coast, easily ground to powder and transported in suspension by sea water. Observation indeed confirms these deductions.

With the rising of sea level and related encroachment of the waters over the continent, the littoral beds deposited amidst agitation and turmoil have been covered by an increasing depth of water and therefore submitted to a more quiet environment. Under such conditions the marine organisms carrying a weak protection and which dislike movement began to populate that area. The point X in figure 3 is the upper limit of the sea bottom inhabited by shells. It may be seen that its distance to the coast B depends on the depth VX, lower limit of the strong agitation which has been assumed earlier not to exceed 50 ft. But the organisms living close to that limit should have been occasionally submitted to the action of the strongest movements of sea water. Also variable amounts of fine sand should have remained in suspension long enough to reach such depths. Therefore a certain amount of sand similar to the overlying one should be associated with these first shells. Indeed, without exception, wherever a bed of shells rests on a layer of sand there is a reciprocal admixture along the contact, the first layers of sand containing shells and the last beds of shells being mixed with sand.

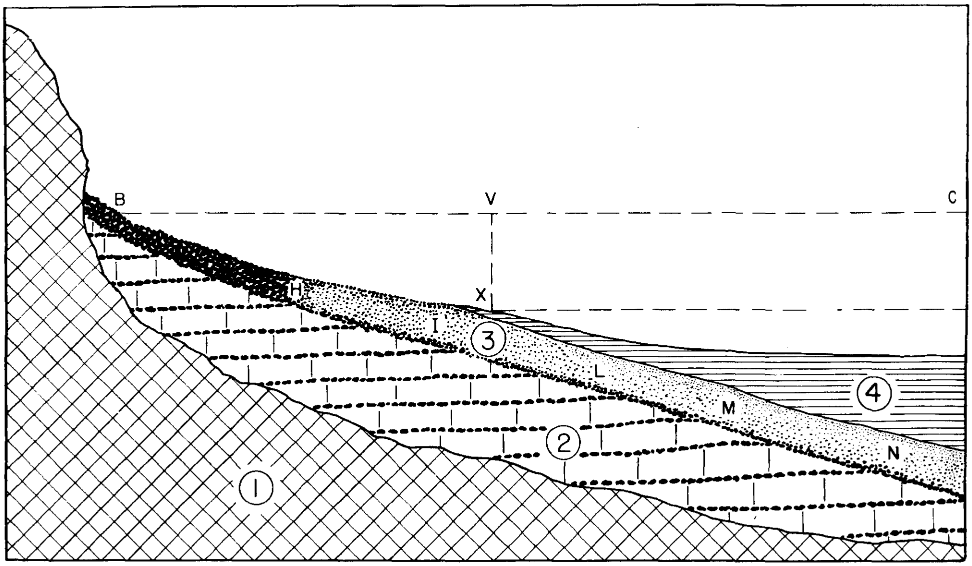

FIGURE 3. Conditions of the littoral beds originating from the erosion of the cliffs of chalk when the seashore reaches the foot of the mountains of older rocks.
3. Littoral beds deposited in rising sea.
4. *Upper horizontal calcareous pelagic beds.*

With the continued encroaching of the sea and related inland migration of the coast, the succeeding marine organisms have been submitted to a more quiet environment and eventually to stagnant condition. Therefore, undisturbed generations of shells could follow one another and gradually build in the course of centuries very thick layers consisting entirely of calcareous material. The upper surface of these beds should tend to become more and more horizontal with increasing distance from the coast.

While the deposition of countless generations of shells was proceeding slowly in deeper water, the encroaching sea should eventually have reached the foot of the high mountains and started eroding them. The blocks of quartz and siliceous rocks generated by this process were rolled into pebbles and eventually through further abrasion converted into sands of variable grain-size. The coarsest were immediately deposited at the coast, the finer ones at a lower level and finally the most divided materials settled the farthest away, generating very fine-grained deposits which resemble clay.

Figure 4 shows the sea reaching the foot of the mountains. The lower littoral beds, which consist of pebbles, sands and marls and were generated through erosion of the cliff by the encroaching sea, are overlain by the upper horizontal calcareous pelagic beds deposited while the shoreline was moving farther away. The upper littoral beds which originated through the erosion of the mountains build an apron of rounded quartz pebbles gradually mixed downwards with coarse sands and with an increasing amount of finer matters in the direction of G. These conditions result from the properties of the finely divided materials to remain longer in suspension and therefore to be deposited farther away from the shore.

Eventually, after many centuries, the sea having reached its maximum elevation, remained stationary and began to recede. During this withdrawal a complete washing of the materials accumulated at the foot of the mountains took place. The heaviest components like the rounded pebbles of quartz and associated coarse

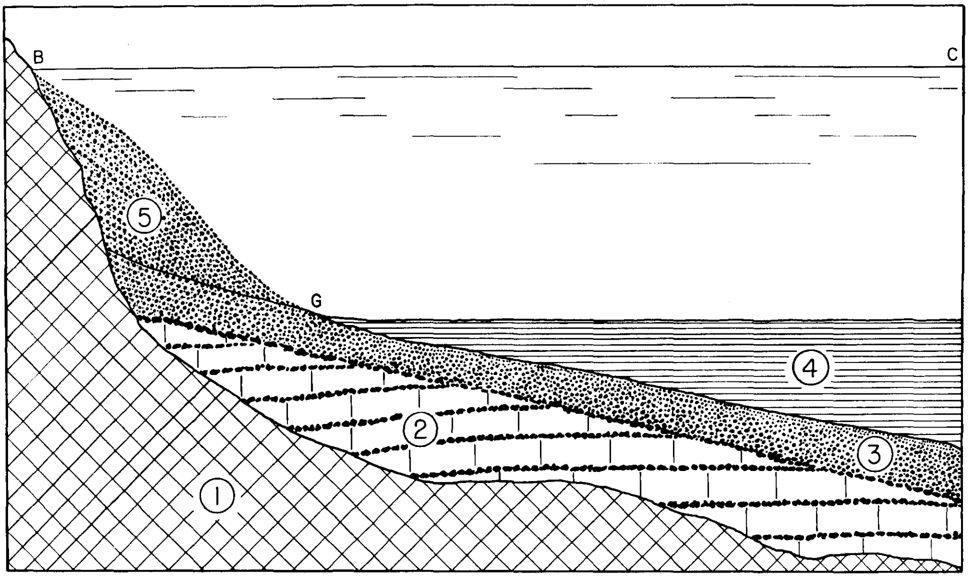

FIGURE 4. Deposition of the littoral beds originating from the erosion of the mountains of older rocks.
3. Lower littoral beds.
4. Upper horizontal calcareous pelagic beds.
5. Upper littoral beds.

sands were first uncovered but not carried away by the waters. However, the light and divided materials, like the very fine sands, silts and clays, followed the withdrawal of the waters in which they were able to remain in suspension for a certain time. Therefore the retreating sea should have scattered over the pelagic beds a sheet of sandy and argillaceous materials. Because of depositional processes this blanket of detrital materials should gradually decrease in thickness away from the high mountains and eventually disappear.

I shall call these deposits *littoral beds formed in receding sea* in order to distinguish them from similar ones formed *in rising sea* as shown in figures 5 and 6. Both kinds of littoral beds typically converge toward one another landwards and eventually join at point I, conversely they diverge from one another oceanwards. Their reciprocal distinction is very easy because the upper ones always consist of debris derived from the older rocks of the high mountains whereas the lower ones contain only materials eroded from the horizontal pelagic beds or chalk.

The horizontal calcareous pelagic beds should remain protected by their overlying sandy layer as long as sea level remained high above them (fig. 5). However, erosional processes should become active with increased lowering of sea level and bring about their destruction. For instance (fig. 6), whenever a line *bc* has been reached cliffs should be carved at *ux* in the pelagic beds. Eventually after a variable span of time the sea, having reached a line *b'c'* located underneath the calcareous pelagic layers, should begin to erode the lower littoral beds deposited during its rising phase. The action of the waves should easily destroy these poorly consolidated sands and argillaceous beds as well as the overlying pelagic beds by undermining them. Although in receding phase the sea might occasionally have encroached on the coasts and the cliff originally located at *ux* should have retreated at a variable distance such as VX depending on local factors which cannot be detailed here.

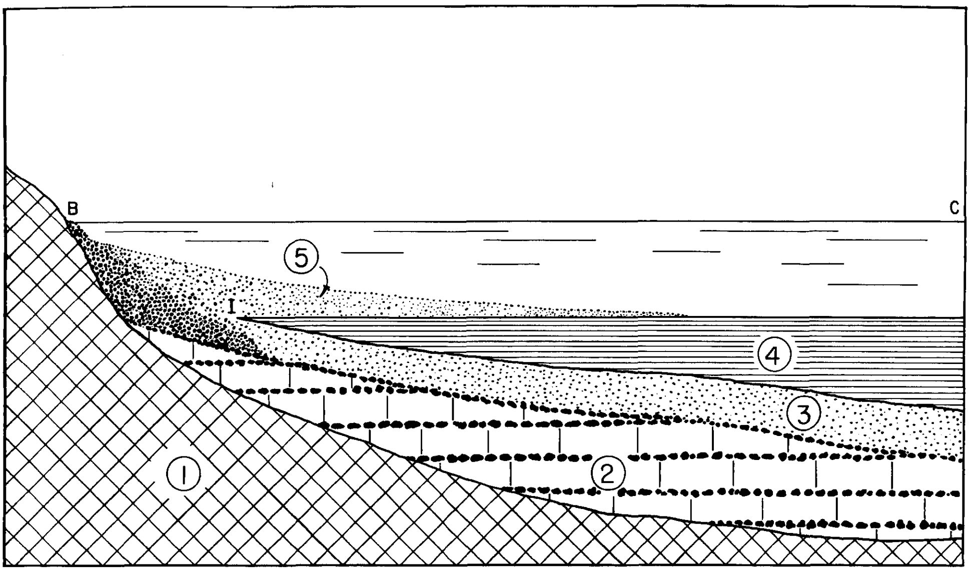

FIGURE 5. Deposition of littoral beds through washing of the materials by a receding sea.
3. Lower littoral beds formed in rising sea.
4. Upper horizontal calcareous pelagic beds.
5. Upper littoral beds formed in receding sea.

The result of these processes has been the destruction at numerous places of the littoral and pelagic beds overlying the chalk, particularly in the vicinity of the present sea level. Generally only the chalk or the lower littoral beds have been preserved as shown along the coasts of Normandy, Picardie, and parts of England.

The facts discussed above were supposed to demonstrate a very slow oscillatory movement of the sea, a kind of ebb and flow requiring several hundred of thousand years for completion and which should already have been repeated a certain number of times. Therefore a cross-section of the horizontal beds located between the sea and the high mountains should display alternating littoral and pelagic beds. These well-characterized layers consisting of entirely different materials should be mixed near their points of contact but uncontaminated a short distance away. By extending the cross-section downwards to the substratum of older rocks, the number of marine oscillations could be told by the number of beds.

Finally, wherever the upper layers were deposited on top of weakly consolidated sands and clays they should have been often destroyed by the action of the receding sea leaving only the lower beds.

This is the picture which should occur according to my initial hypothesis. If such a situation does really exist; if the materials abandoned by the sea appear indeed as alternating beds undoubtedly formed either in open sea or along the shores; if everywhere observation confirms theory, then my hypothesis is a truth in agreement with the processes of nature, a fact resulting from experience and a conclusion reached through observation. Adequate proofs could be afforded by describing a portion of the formations of France and England, but since too many details would be cumbersome in this first memoir, I shall only describe a few sections in France which everyone can easily check.

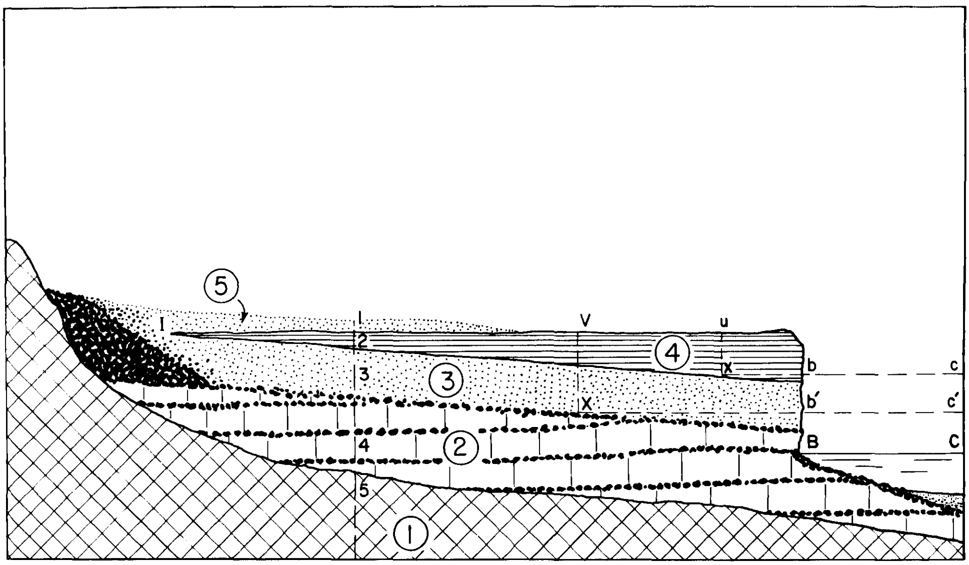

FIGURE 6. Conditions of occurrence of littoral and pelagic beds in a part of France. Same legend as preceding figure.

Section A of figure 7 has been measured in the mountains near Villers-Coterets. From top to bottom may be observed:

1. A bed of sand which often contains rounded pebbles and has been locally cemented into a sandstone. No debris of marine organisms are present although sometimes in the upper part imprints of a species of freshwater buccin and of *cornets de Saint-Hubert* occur on pebbles or on white argillaceous cherts. In my opinion this bed has been formed at the coast in a receding sea . . . . 260 ft
2. Beds of calcareous rocks of variable thickness obviously deposited in open sea and consisting entirely of shells, debris, and hard parts of marine organisms. Large screws oriented horizontally and reaching 2 ft in length occur frequently . . . . 75 ft
1. A sand body with rounded pebbles containing in its upper part shells and abundant petrified wood. This bed has been deposited at the coast in a rising sea. The reasons for the occurrence of the shells and petrified wood in the upper part of the bed have been explained earlier. The thickness is variable but estimated at 60 ft

4. The chalk underlying these different beds. Since the upper surface of the chalk is in general irregular, it occurs only at a rather great depth in the vicinity of Villers-Coterets and therefore is not exposed in the county. It begins to outcrop a few leagues to the N and NW in the forest of Compiègne and extends over all Picardie, Normandy, the coasts of England, etc. Nowhere does the chalk reach a thickness of more than 300 to 400 ft, hence 350 ft

Total . . . . .745 ft

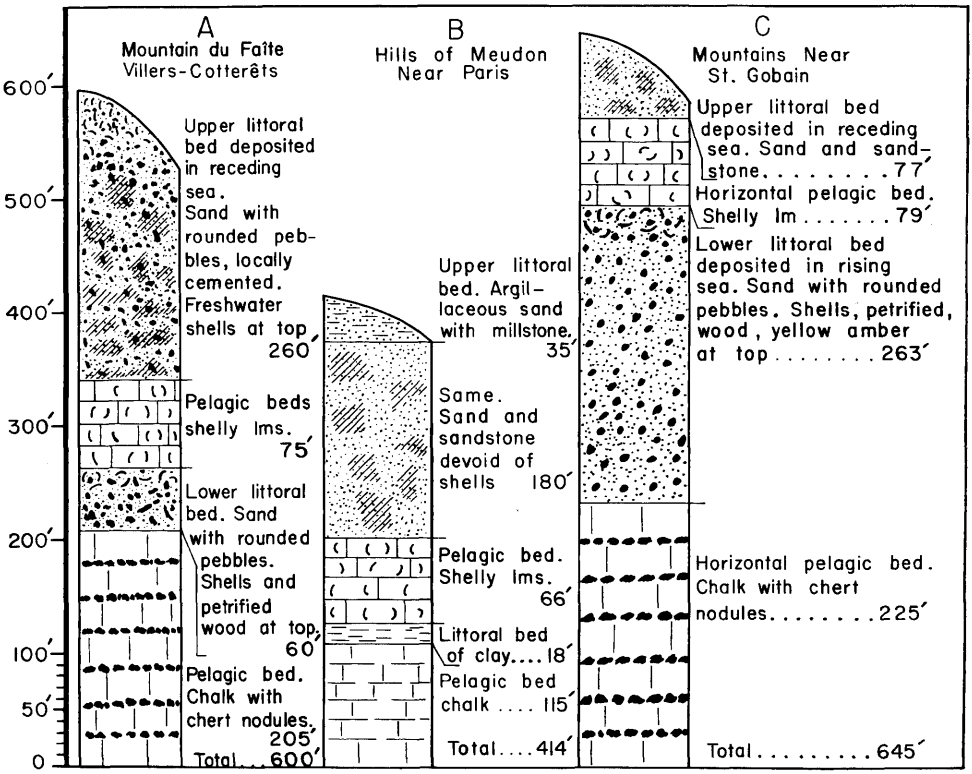

FIGURE 7. Typical columnar sections in the Paris Basin.

Perfect similarity is shown by a comparison between this column and the cross-section of figure 6. The beds forming the mountains in the vicinity of Villers-Coterets occur exactly in the same order as the layers 1,2,3,4 and 5 of the cross-section located half-way between the mountains and the sea.

Another striking similarity may be noticed in the sequence of beds in the vicinity of Meudon, near Paris, particularly on the way down to the glass factory of Sèvres. The following layers appear below the soil in the upper part of the park (section B) figure 7:

1. Argillaceous sand containing patches of millstone . . . . .25 ft
2. Sand and sandstone . . . . .180 ft
3. Beds of calcareous rocks consisting entirely of shell debris . . . . .66 ft
4. Yellow clay . . . . .18 ft
5. Chalk . . . . .115 ft

Total down to stream level .404 ft

Again this column is almost identical to the sequence of beds 1,2,3,4 and 5 in the cross-section of figure 6. The only visible difference is shown by the bed separating the calcareous rocks from the chalk which consists of clay instead of sand and is also thinner than in the mountains near Villers-Coterets. I shall explain somewhere else the reasons for this situation.

A third example is a section of the mountains in the vicinity of la Fère, near Saint-Gobain (section C, fig. 7). In the woods of Prémontré and of Saint-Gobain the following beds occur:

1.	Sand and sandstone below the soil	76.5 ft
2.	A bed of impervious argillaceous sand	1 ft
3.	Bed of calcareous rock consisting of debris of shells and of marine organisms	79 ft
	Blue clay	1 ft
	Sand with rounded pebbles	120 ft
	Clay	3 ft
	Repetition of the sand with rounded pebbles	139 ft
	Chalk which has been penetrated very deeply with an auger	224 ft
	Total	643.5 ft

The base of this column is 200 ft below the level of the river Oise at la Fère.

The cross-section of figure 6 with its layers 1,2,3,4 and 5 can again be recognized here. For instance, the upper bed of sand and sandstone No. 1 deposited at the coast in a receding sea; bed No. 2 consisting of calcareous rocks formed in the open sea; bed No. 3 of sand deposited along the coast in a rising sea; finally the chalk No. 4 which seems to have been formed in open sea.

Undoubtedly questions shall be raised about the substratum of the chalk and the meaning of the term "older rocks." This designation which I have borrowed from Mr. Rouelle does not imply well-defined ideas. Most certainly the so-called older rocks consist also of an association of littoral beds and do not represent the primitive earth.

Nevertheless it is remarkable that the chalk is usually the last bed containing shells, marine organisms, and remains of living animals. The underlying shales often display floated materials like wood and plants stranded on its shore and even a few imprints of fish but no shells. These are also absent from the beds which seem to have been formed in open sea at the same time. If an explanation had to be offered of this strange situation, I would conclude with Mr. Monge that the earth has not been always populated by living organisms but was for a long period of time an inanimated desert. Vegetation appeared long before animals or at least trees and plants covered the earth before the seas were populated by shells. I shall discuss in the future, in great detail, these ideas which belong more to Mr. Monge than to myself, but a clear presentation of the fundamental observations on which they are based appeared indispensable.

It is indeed difficult in front of such perfect agreement between theory and observation, demonstrated everywhere by the beds deposited or formed by the sea, to consider the advancing and receding movement of the sea as an hypothesis instead of a factual truth and a direct result of observations. It belongs to the physicists who have so cleverly investigated all aspects of physics and astronomy to give us an explanation of the causes of these oscillations, to tell us if they still take place or if possibly an equilibrium might have been reached after a long sequence of centuries. A very small change in the orientation of the axis of rotation and consequently in the position of the earth's equator would be sufficient to account for all these phenomena. However, this fundamental question pertains to physical astronomy and is not of my resort.

In this memoir I have presented only general considerations and actually only one aspect of the problem I had planned to solve because its complexity prevented a complete discussion. I have admitted for instance that the littoral beds (fig. 2,4,5, and 6) deposited at the coast in rising sea should always consist of sand and pebbles overlying the chalk as observed along the coasts of England and Normandy; that the chalk itself should always contain chert nodules. Obviously under these conditions the debris generated by the action of the sea at the expense of the chalk should consist of cobbles, rounded pebbles, and sand. However, quite frequently the chalk being devoid of chert nodules the sea does not deposit sand along the coast, but a yellow clay which originally occurred in small amount in the chalk itself. Often also the last calcareous beds do not consist of pure chalk but of calcareous earth containing a variable amount of clay or sand, elsewhere the seashore may consist of quartz and shales. Consequently the beds formed along the coast in rising sea vary in composition according to local circumstances. Only through an individual examination and discussion of each case is it possible to grasp the entire problem and to realize the great variety of results originating from a unique and simple cause.

Therefore I shall discuss the littoral beds in a particular memoir; the circumstances of their deposition, the varieties they display according to local and peculiar circumstances and particularly in relation to the composition of the layers from which they have been derived. I shall demonstrate that only the littoral beds should contain floated materials like wood, yellow amber, and plant remains. Also along the coast should occur most of the precipitated ores because whenever the waters which carried metallic salts became mixed with sea water, double decompositions and precipitations took place and deposited metals as oxides or insoluble salts.

I shall also gather in another memoir my observations on the beds formed in open sea, on the kinds of shells and marine organisms they contain, on the depth conditions and distance to the shore necessary for the existance of each type of life.

DISCUSSION

Lavoisier's distinction between pelagic (deep-sea) and littoral organisms and deposits which he originally borrowed from Rouelle was afterwards adopted by Lamarck (1802). It has been quoted ever since in most books on the history of geology (Geikie, 1905; Mather and Mason, 1939) as Lavoisier's major contribution whereas it was only a practical division he used to demonstrate the concept of transgressive and regressive overlaps. As Comte (1949) pointed out, Lavoisier not only described the mechanical distribution of littoral sediments, by decreasing grain-size with increasing depth and distance to shoreline but he related it to the idea of a shore profile of equilibrium. Geometrically this profile is more a segment of hyperbola than of parabola because it tends to become asymptotic at a finite distance corresponding in fact to wave base. Lavoisier's relation between littoral erosion and deposition was certainly the forerunner of the modern studies on the equilibrium of coast lines.

Similarly, by combining in his study transgressive and regressive overlaps, Lavoisier explained the significance of basal conglomerates and reached the modern concept of sedimentary cycle. However his discussion and illustration of that concept, identical in all aspects to our modern views (compare his figure 6 with Grabau's figures 1 and 6), after having been fully noticed by Desmarest (1794) and recently by Comte (1949), have fallen into complete neglect. This situation is typically shown by the fact that historians of geology always quote or reproduce figure 1 showing the littoral beds (Mather and Mason, 1939, fig. 9, p. 127) but never figure 6 which illustrates overlaps.

The detailed sections which accompany Lavoisier's essay gave the first outline of a correct classification of the Tertiary deposits of the Paris basin. His sketch clearly outlined in their true sequence the chalk supporting the Plastic Clay, lower sands, Calcaire Grossier, upper sands and upper lacustrine limestone (meulière). Only the middle group of lacustrine marls and gypsum is missing from his sections, being included in the Calcaire Grossier. A comparison between the description of the sections and their graphic representation (fig. 7) shows some discrepancies in thicknesses and in the number of beds for which no explanation is available.

Again these observations in spite of their exactitude did not have the deserved impact on the understanding of the stratigraphy of the Paris basin because they were out of context at the end of a theoretical study. They were, however, to be brilliantly confirmed by the works of G. Cuvier and A. Brongniart (1808). It is interesting to point out that their description of the section at Villers-Coterets was not so correct as that of Lavoisier although his name was not quoted in their work.

REFERENCES

D'Archiac, A. 1864. Introduction à l'étude de la paléontologie stratigraphique. Savy, Paris. Vol. 1. 491 p.

Comte, P. 1949. Aperçu sur l'oeuvre géologique de Lavoisier. Annales Soc. Géol. Nord. **69**: 369–375.

Cuvier, G. and **A. Brongniart.** 1808. Essai sur la géographie minéralogique des environs de Paris. J. des Mines. **23**: 421–458.

Desmarest, N. 1794. Encyclopédie méthodique, Géographie Physique, Paris. **1**: 783.

Geikie, Arch. 1905. The founders of geology. Macmillan, London. 486 p.

Grabau, A. W. 1906. Types of sedimentary overlap. Bull. Soc. Geol. Am. **17**: 567–636.

Guettard, J. E. 1780. Atlas et Description Minéralogiques de la France, entrepris par ordre du Roi par MM. Guettard et Monnet.

Lamarck, J. B. 1802. Hydrogéologie. Agasse, Paris. 186 p.

Lavoisier, A. 1789. Observations générales sur les couches horizontales, qui ont été déposées par la mer, et sur les consequences qu'on peut tirer de leurs dispositions, relativement à l'ancienneté du globe terrestre. Mém. Acad. Roy. Sci. (1789): 351–371.

Mather, K. F. and **S. L. Mason.** 1939. A source book in geology. McGraw-Hill, New York. 702 p.

Smeaton, W. A. 1963. New light on Lavoisier: the research of the last ten years. History of Science. Heffer, Cambridge. **2**: 51–69.